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the whole system of our localizing reactions becomes through these considerations more complex by far than the schematizations of the text-books propose. But physiological optics has shown at every point in its development that mere simplification has not always meant a deeper insight into the real relations.

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NOTE ON THE PHYSICAL WORLD-ORDER.[1] I

IT is a matter of common experience that we know something of the meaning of the term *body* and of the distribution of *bodies in space and time* before we are acquainted with those physical laws which, where they are known, enable us to describe bodies in new ways and to arrange them in that system which we call the physical world.

The task of discovering these laws, of effecting these descriptions, of constructing this system, belongs to a group of sciences, which, though differing *inter se,* we are accustomed to include under the single name of *physical science.* I say we are accustomed to refer to a single physical science; I mean we constantly hear such questions as these: What is the *physical basis* of life? How far are differences of civilization due to *physical,* how far to economic, etc., causes? These and similar questions lead us to contrast a science of physical causes with such sciences as biology, psychology and sociology. But just what sciences are included under the head of the physical, and on what ground they are included is by no means an easy matter to determine. Perhaps all would admit to this class the sciences of physics and chemistry; some, with Helmholtz, would include geometry; others, with the 'mechanists,' would include biology. But even if we confine ourselves to general physics and chemistry, there are still to be noted wide differences in method. Between mechanics, say, and chemistry, these differences are of sufficient importance to make the problem of finding a common nature in the two branches of science an extremely difficult one.

Nevertheless, I think we can frame a definition which, if applied to the sciences actually known, would bring into one class those which are usually included under the head of physical science, and explain the uncertainty in which we remain concerning others.

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[1] This article was prepared at the request of Professor George S. Fullerton, who, with the author's permission, has appended it as a *Note* to his work 'A Treatise on Metaphysics' (*in press*). The thanks of the author are extended to Professor Fullerton and to his publisher, The Macmillan Co., for their courtesy in authorizing the publication of this *Note* in its present form.

I venture to say, then, that *a physical science is one which employs in its description of nature only such terms as can adequately be defined by the use of the measuring rod.*

What is here meant by the *description of nature* offered by a science will best be understood if we consider a typical scientific problem: Given a group of bodies, in which are to be found certain conditions, such as position, volume, mass, temperature, etc., what changes of condition are these bodies going to undergo? To answer this question we should have to be in possession of a law which connects these conditions with one another and with time. The *description of nature* offered by a science is nothing other than the law or series of laws which it has formulated.

Now, our definition asserts that such a law is a physical law, if to understand its meaning and to verify its truth no knowledge is presupposed other than such as is involved in the use of the measuring rod. In examining the application of this definition to known sciences, its import will be seen more clearly.

The use of the measuring rod, *i. e.,* the description of the procedure by which we may determine the ratio of two lengths, is established in certain of the axioms of geometry. All the axioms are not devoted to this description; some explain the way in which, knowing how to determine the ratio of two lengths, we may determine the relative magnitudes of two angles. We may say, therefore, that all that portion of geometry which is not a definition of measurement, but which records the results of measurement, falls under our definition of a physical science.

Next, let us turn to the science of mechanics, and by way of fixing our thoughts we may consider a particular law of mechanics, say, the law of gravitation. This law is of such a nature that in order to apply it to a group of bodies we are obliged to know the mass of each body, its position, and the velocity with which it is moving. Applying the law, we can calculate the values which these conditions will assume at any moment. Now, of the terms used in this description, the positions of the bodies would evidently be determined by the use of the measuring rod in conformity with the principles of geometry; but when we describe the motion of bodies we are obliged to introduce such terms as velocity and acceleration. These terms stand for quantities and are susceptible of measurement, but in determining their values it is not sufficient to measure space magnitudes; we are obliged also to measure periods of *time.* It may not at once be apparent in what sense time can be determined by the use of the measuring rod; yet the physicist defines time as the hour-angle of a certain star, and this angle is, in the last resort, determined by measurements of length. Time, therefore, and consequently such ratios of space and time as velocity and acceleration, are determined by the use of the measuring rod.

Finally, in our mechanical example we have had to make use of the term *mass*. This once more appears in our law as a quantity susceptible of measurement; but in what sense can this measurement be effected by the use of the measuring rod? The mass of a body is not determined by its geometrical form or by its volume, for two bodies of exactly the same form or of the same volume may have different masses ascribed to them; and to suppose with Democritus that bodies are made up of atoms which themselves differ in mass only as they differ in volume, would carry us beyond the limits of scientific experience. It is not necessary to introduce any venturesome hypothesis in order to understand in what sense the physicist's determination of the mass of a body depends solely upon measurements of length. Indeed, in the simplest instrument for determining mass, *viz.*, the balance, it is at once evident that no observations are made except observations of position. This, to be sure, is a determination of mass under particular conditions; but it can easily be shown that the most general definition of mass which the physicist can frame is stated in terms of positions and motions involving only such quantities as can be determined by the use of the measuring rod.[2]

It is clear, then, that if the science of mechanics were nothing but an application of the law of gravitation, it would fall within the class of physical sciences as here defined. Now, although the science of mechanics may include other laws than that of gravitation, these other laws must yet resemble the law of gravitation in that the only terms which they employ are ultimately definable in terms of mass, length and time. What has been said, therefore, of these terms as they occur in the law of gravitation, might be said of them with equal truth as they occur in any other law of mechanics. So that we may conclude that the science of mechanics employs in its description of nature only such terms as may be understood by the use of the measuring rod, and that consequently it falls within our definition of a physical science.

The other sciences that are ordinarily recognized as physical build on the mechanical basis, *i. e.*, the new terms which they introduce into their description of nature involve in their definition the three whose meaning has been fixed by mechanics. A complete description of these new terms would lie outside the plan of the present paper. We may, however, indicate the lines which such a discussion would follow, by considering the sense in which the *units* introduced into general physics are in the end determined by the use of the measuring rod.

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[2] *Vide* Mach, 'Mechanics in its Development,' ed. 2, p. 243.

Thus, a *unit quantity of heat* is the quantity required to raise a unit mass of water one degree centigrade. The term 'mass' we have already considered: it need hardly be pointed out that the ordinary measure of temperature—the expansion of a mercury column—is a linear one, while a degree of absolute temperature is defined by Thompson in terms of mechanical work. Again, *a unit quantity of electricity* is the quantity which acts on a similar quantity with unit force at unit distance. Now a unit force is one which would impart to unit mass a unit acceleration. The measure is therefore based upon mechanics, and the instrument actually used in the measurement, say Coulomb's tortion balance, is read in degrees of arc. As a last example, a *unit atomic mass,* though difficult to define, involves no measurements save those which determine mass and volume.

These units which enter into the different physical sciences reveal in a characteristic way the nature of the sciences. It is only when we are in possession of the fundamental laws of a science that we can define the meaning of such units. This discussion of them will suggest the way in which a complete examination of the physical sciences with respect to their definition would have to be made. I shall take it to be sufficiently established for our purpose that physical sciences describe nature in terms whose meaning depends wholly on the use of the measuring rod. So defined, we see that they would include the known sciences of mechanics, general physics, and chemistry; but what sciences, if any, would such a definition exclude?

Suppose one were asked: What is the future of republican institutions? or, What is the cause of the decay of the drama? Would a reasonable person be likely to arm himself with a foot-rule with which to discover the answers to these questions? And yet such questions have a meaning. The demand of the one for prediction and of the other for explanation is a scientific demand, and a scientific effort can be made to meet it. Only it seems scarcely sensible to ask one to put these problems in such wise that a measuring rod would play any part in the solving of them.

Take another question: Why did the picture of a summer day in another land come into my mind just now as I looked out upon a bleak landscape? I search among my ideas for *links of association.* The law of association with which I am for the moment satisfied can apparently not be expressed in terms reducible to space measurements. Even the observation of living organisms whose simpler forms behave in a way that we are more and more inclined to regard as determined by physical and chemical laws, gives rise to terms and laws that seem to have no reference to the foot-rule. *Habit,* *inheritance, variation, natural selection,*—these terms mean something, they describe conditions we can recognize; the laws have a significance, on the basis of given conditions they serve us in prediction and explanation. We are evidently dealing with a science, but with one which appears to fall without our definition of a physical science.

It would seem, then, that there might be sciences pursuing methods other than physical—at least there is a reason for thinking so sufficient to have given rise to interesting problems concerning the possible limits of the physical image of nature. For example, the question has often arisen in the history of reflective thought: To what extent have we a right to expect that for every definable natural phenomenon a physical explanation may be found? We may illustrate the meaning of the question, as well as indicate its answer, by a particular example.

We said that physical science devotes itself to the study of objects in space and time, so far as their behavior is ultimately describable in terms of the measuring rod. Among the bodies whose behavior is thus describable are the bodies of our fellow men and our own. The body of my neighbor yonder would fall from a height to the earth with the same acceleration as would a stone. The physics and chemistry of the process of nutrition, secretion, etc., going on in his body are becoming better known. Even that portion of its activity which we are accustomed to regard as deliberate, and which sufficiently distinguishes his body as animate and conscious, may still resemble the behavior of an inanimate machine in its obedience to such laws as that of the conservation of energy. Have we not, therefore, every reason to suppose that, with advancing science, that particular natural phenomenon,—the behavior of a given human being,—will receive a physical explanation?

No sooner, however, do we conceive a hope of receiving a physical answer to the kind of question respecting our neighbor's behavior that we have instanced, than it occurs to us that there are many questions respecting such behavior to which we would not expect a physical answer. The beautiful old illustration that Plato gives in the Phædo will serve us here. Socrates, it will be remembered, was sitting in prison awaiting his execution. The painful interval remaining was to be whiled away in pleasant discourse with his disciples on the immortality of the soul. In the course of the discussion Socrates is led to consider in what different ways things may be explained. He recalls the enthusiasm with which he first learned that Anaxagoras, instead of resting satisfied with the old order of mechanical causes, had sought to show how 'mind was the disposer and cause of all.' But he was quickly undeceived:—

"What hopes I had formed, and how grievously was I disappointed! As I proceeded, I found my philosopher altogether forsaking mind or any other principle of order, but having recourse to air, and ether, and water, and other eccentricities. I might compare him to a person who began by maintaining generally that mind is the cause of the actions of Socrates, but who, when he endeavored to explain the causes of my several actions in detail, went on to show that I sit here because my body is made up of bones and muscles; and the bones, as he would say, are hard and have ligaments which divide them, and the muscles are elastic, and they cover the bones, which have also a covering or environment of flesh and skin which contains them; and as the bones are lifted at their joints by the contraction or relaxation of the muscles, I am able to bend my limbs, and this is why I am sitting here in a curved posture; that is what he would say, and he would have a similar explanation of my talking to you, which he would attribute to sound, and air, and hearing, and he would assign ten thousand other causes of the same sort, forgetting to mention the true cause, which is, that the Athenians have thought fit to condemn me, and accordingly I have thought it better and more right to remain here and undergo my sentence; for I am inclined to think that these muscles and bones of mine would have gone off to Megara or Bœotia—by the dog of Egypt they would—if they had been guided only by their own idea of what was best, and if I had not chosen as the better and nobler part, instead of playing truant and running away, to undergo any punishment which the state inflicts. There is surely a strange confusion of causes and conditions in all this. It may be said, indeed, that without bones and muscles, and the other parts of the body, I can not execute my purposes. But to say that I do as I do because of them, and that this is the way in which mind acts, and not from the choice of the best, is a very careless and idle mode of speaking. I wonder that they can not distinguish the cause from the condition, which the many, feeling about in the dark, are always mistaking and misnaming."

There is here a physical situation which Plato roughly outlines, but to have this situation pointed out to us in reply to our question, Why, Socrates, are you sitting here? strikes us as droll. Besides the physical questions respecting Socrates' behavior and the physical answers which in the course of time we may hope these questions will receive, there would seem to be other questions which are not physical, and to which we can neither hope for, desire, nor conceive a physical answer.

To reconcile these two points of view an assumption has sometimes been made which will illustrate very well one sense in which physical science has been supposed to be of limited application to nature. The assumption is,—and we may suppose Descartes to make it,—that in spite of the fact that most of the behavior of a human body is capable of explanation in terms of physical science, yet not all of its behavior is so. Even if we were in possession of the most complete physical knowledge, a part of that behavior would remain unpredictable on physical grounds. This part is not, perhaps, inexplicable, but if we try to explain it, it must be in terms which have no physical meaning, *e. g.,* in terms of *motives.* In our example it was the suggestion of a physical explanation for this part of Socrates' behavior which furnished the comic element in Plato's sketch.

This way of looking at the matter would seem to be intelligible, at least. We find a ship propelled by a physically describable machine, but to explain its whole behavior we should have to take into account the helmsman, who is no part of that machine. The human body is analogous. It is a machine directed by a soul, which is no part of that machine. The part of this conception which demands our immediate attention is not the introduction of the soul, but the hypothesis of an incomplete physical machine. We are not concerned with the adequacy of the non-physical filling, but with the assumption of the physical gap. The assumption is, that part of the behavior of an object in space and time can not be explained in physical terms.

With regard to this hypothesis I need not ask, Is it true? but rather, Is it intelligible? Does it really mean anything? In the first place, it will be noted that the hypothesis in question is not an attempt to point out our actual inability to give a physical explanation of a certain phenomenon. This inability every one would admit. The point of the whole hypothesis is that the phenomenon is assumed to be essentially inexplicable in physical terms. What, we ask, does *essentially inexplicable* mean in this connection?

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DISCUSSION

OF 'TIME PERCEPTION'

I

DR. MONTAGUE'S theory of time perception, and the discussion it has called forth, have been most interesting and instructive.

I find myself especially sympathetic with Dr. Montague's general view of consciousness, and therefore feel the more hesitancy in